Carbonate rock physics modelling at ultrasonic and seismic frequencies

Zizhen Wang a, Ruihe Wang a, Douglas R. Schmitt b, Yaoqi Zhou a, Feifei Wang a

a China University of Petroleum, Qingdao, China; b University of Alberta, Edmonton, Canada
Contact email: wangzzzh@upc.edu.cn

Introduction

Carbonate reservoirs contain nearly 60% of the world total oil and gas reserves. But carbonate rocks display significant heterogeneity at different scales due to their complex pore systems. It is difficult to obtain representative carbonate samples and to satisfactorily quantify their pore structures. Consequently, carbonate rocks have not been intensely investigated from the experimental rock physics perspective. As the development of computers and digital rock technology, numerical modelling has become an important complement to real core measurements in lab. We build 2D geometrical models containing the pore structure information of porous rocks based on the digital images (such as thin section, SEM, CT, etc.) of real carbonate rocks. And then the modelings by finite element method at ultrasonic (~10^6Hz) and seismic (10-100Hz) frequencies are carried out, respectively.

Method

(1) Geometrical model of porous rocks
Irregularly shaped pores resemble the reality, but greatly increase the numerical calculation burden and even result in failure of convergence for a transient problem modelling. Here, different pore shapes are modelled by regular elliptical pores with different major axis and aspect ratio. Elliptical pores are arbitrarily orientated and randomly distributed in the matrix (Wang et al., 2015). The pore parameter data are from thin section images of real samples using digital image analysis (Figure 1a).

(2) Modelling at ultrasonic frequency
We model the pulse-transmission velocity measurements in the laboratory and analyze the effect of pore structure (porosity \( \phi \), pore aspect ratio-\( AR \), pore size-\( d \)) on the elastic wave velocities in carbonate rocks (Figure 1b). The solid matrix is isotropic linear elastic. The pores are filled with incompressible fluid. An excitation pulse signal with ultrasonic frequency is applied on the transmitting boundary as a source of compressional wave pulse. Receiving points are equidistantly located on the side opposite to the source. The velocity of the modelled sample is calculated as the ratio of its length to the time delay between the source and received signal.

(3) Modelling at seismic frequency
We model the dynamic moduli of porous rocks saturated with viscous fluid at seismic frequencies on core scale based on the stress-strain method (Spencer, 1981) (Figure 1c). The solid matrix is isotropic
linear elastic. The elastic moduli dispersion of viscous fluid is described by the Maxwell’s spring-dash pot model. At one end of the sample, a sinusoidal normal stress with seismic frequency is applied. The other end of the sample is fixed. The corresponding stress and strain in y-direction at the loading end are calculated. And then, the phase lag ($\delta$) between the y-strain and the y-stress, the storage modulus ($E'$) are calculated according to the stress-strain method.

![Figure 1: carbonate rock physics modelling, (a) geometrical model, (b) pulse-transmission modelling at ultrasonic frequency, (c) dynamic stress-strain modelling at seismic frequency](image)

**Results**

The accuracy of modelling at high frequency has been verified by experiment measurements in real carbonates. The modelling at ultrasonic frequency indicate that the P-wave velocity increases as a power function as the pore aspect ratio increases. The velocities of carbonate rocks with complicated pore geometries (low $AR$, small $d$) is much slower than that of rocks with simple pore geometries (high $AR$, large $d$). The modelling results at seismic frequency indicate that the frequency and the fluid viscosity have similar effects on the dynamic moduli dispersion of fully saturated rocks. We observed the Debye peak in the phase lag variation with the change of frequency and viscosity. The viscoelastic properties of saturated rocks are more sensitive to the pore aspect ratio.

**Conclusions**

Numerical modelling of carbonate rock physics based on digital images of real rocks could provide reasonable results which is a helpful complement to the insufficient lab measurements. Modelling at ultrasonic frequency which simulates the pulse-transmission measurements has been verified by lab observations. Modelling at seismic frequency which mimics the dynamic creep or relaxation tests is still preliminary and need to be verified by further lab measurements.

**References**
